TIDAL AND FLOOD HYDRAULICS STUDY

Prepared for

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EXECUTIVE SUMMARY

A finite element RMA2 numerical model was constructed to quantify existing hydrologic conditions at Colorado Lagoon. The purpose of this study was to characterize the existing lagoon hydraulics under both wet and dry weather conditions. The model is sufficient operating and calibrated to use for evaluating restoration alternatives as a future task.

Under the dry weather condition, the model results indicate that low tides in the lagoon were muted under the current condition of an open gate (the gate is lifted as much as possible). The low tides were cut off about 2 feet compared to the ocean tide and tidal circulation is significantly reduced by the culvert compared to Marine Stadium. The mean tidal elevation in the lagoon is slightly above mean sea level about +0.7 feet NGVD29 due to effects of the culvert retarding tidal ebb flows. Tidal fluctuations at Marine Stadium are essentially the same as those in the ocean.

Under a combined condition of a severe storm flood (the 50-year storm) and an ocean high tide with the culvert open, the model indicates that the peak water level in the lagoon reaches +5.7 to +5.9 feet NGVD29, the same elevation as the boundary of the lagoon park area near the intersection of Colorado Street and Eliot Street. Flood protection for this location should be considered for the future.

Based on this hydraulic study, the following recommendations should be considered for future planning:

- Build a flood barrier to provide for 50-year storm flood protection for surrounding properties along Colorado Avenue near Eliot Street;

- Establish operational procedures such that the culvert gate remains completely open to promote drainage, especially during storm events. The City should also check whether a sill exists on the bottom of the culvert entrance to the lagoon and consider its removal to increase flood flow conveyance and improve dry weather tidal circulation.

- Clean the culvert by removing debris/sediment deposits and marine growth on a regular schedule. This will also improve tidal circulation and increase flood flow conveyance, and ultimately lower the flood water level and improve water quality in the lagoon.

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1.0 INTRODUCTION

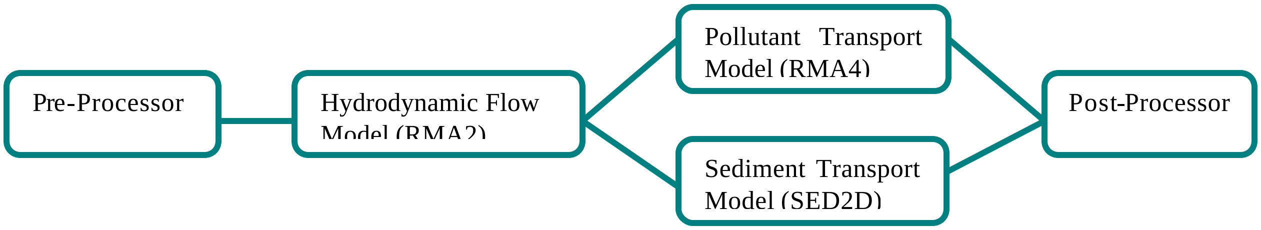
A finite element RMA2 numerical model was constructed. Numerical modeling of tidal and flood hydraulics was performed for the existing conditions of the Colorado Lagoon. The purpose of this study was to characterize the existing lagoon hydraulics under both wet and dry weather conditions. The groundwater flow input into the lagoon was not considered in the modeling since the groundwater level in the vicinity is lower than that in the lagoon. The groundwater movement direction should be from the lagoon. Also, the groundwater movement compared to tidal exchange is negligible. Under the dry weather condition, the local storm drain inputs are not included in modeling as the dry weather flow quantity is negligible compared to tidal exchange through the culvert. A 50-year storm event and a Mean Higher High Water (MHHW) level at the ocean boundary are used in assessing flood flow impacts within the lagoon.

2.0 MODEL SELECTION AND DESCRIPTION

The numerical modeling systems used in this study are summarized in the following sections.

The TABS2 (McAnally and Thomas, 1985) modeling system was developed by the U.S. Army Corps of Engineers (USACE), and consists of two-dimensional, vertically averaged finite element hydrodynamics (RMA2), pollutant transport/water quality (RMA4) and sediment transport models (SED2D). TABS2 is a collection of generalized computer programs and pre- and post-processor utility codes integrated into a numerical modeling system for studying two-dimensional (2-D) depth-averaged hydrodynamics, transport and sedimentation problems in rivers, reservoirs, bays, and estuaries. The finite element method provides a means of obtaining an approximate solution to a system of governing equations by dividing the area of interest into smaller sub-areas called elements. Time-varying partial differential equations are transformed into finite element form and then solved in a global matrix system for the modeled area of interest. The solution is smooth across each element and continuous over the computational area. This modeling system is capable of simulating tidal wetting and drying of marsh and intertidal areas of the estuarine system.

A schematic representation of the system is shown on the following page. TABS2 can be used either as a stand-alone solution technique or as a step in the hybrid modeling approach. RMA2 calculates water surface elevations and current patterns which are input to the pollutant transport (RMA4) and sediment transport (SED2D) models. Existing and proposed geometry can be analyzed to determine the impact of project designs on flow circulation, salinity, water quality and sedimentation in the estuary system. All models utilize the finite element method with Galerkin weighted residuals.



TABS2 Schematic

The hydrodynamic model simulates 2-D flow in rivers and estuaries by solving the depth-averaged Navier Stokes equations for flow velocity and water depth. The equations account for friction losses, eddy viscosity, Coriolis forces and surface wind stresses. The general governing equations are:

Continuity equation:

$$\frac{\P h}{\P t}+\frac{\P (hu)}{\P x}+\frac{\P (hv)}{\P y}=0$$

Conservation of momentum equations:

$$h\frac{\partial u}{\partial t}+uh\frac{\partial u}{\partial x}+vh\frac{\partial u}{\partial y}+gh\frac{\partial a}{\partial x}+gh\frac{\partial h}{\partial x}-h\frac{e_{xx}}{r}\frac{\partial^2 u}{\partial x^2}-h\frac{e_{xy}}{r}\frac{\partial^2 u}{\partial y^2}+S_{f_x}+t_x=0$$

$$h\frac{\partial v}{\partial t}+uh\frac{\partial v}{\partial x}+vh\frac{\partial v}{\partial y}+gh\frac{\partial a}{\partial y}+gh\frac{\partial h}{\partial y}-h\frac{e_{yx}}{r}\frac{\partial^2 v}{\partial x^2}-h\frac{e_{yy}}{r}\frac{\partial^2 v}{\partial y^2}+S_{f_y}+t_y=0$$

where:

u,v = x and y velocity components

t = time

h = water depth

a = bottom elevation

Sf_x = bottom friction loss term in x-direction

Sf_y = bottom friction loss term in y-direction

t_x = wind and Coriolis stresses in x-direction

τ_y = wind and Coriolis stresses in y-direction

ε_{xx} = normal eddy viscosity in the x-direction on x-axis plane

ε_{xy} = tangential eddy viscosity in the x-direction on y-axis plane

ε_{yx} = tangential eddy viscosity in the y-direction on x-axis plane

ε_{yy} = normal eddy viscosity in the y-direction on y-axis plane

For this project study, the RMA2 hydrodynamic model was applied.

3.0 MODEL SETUP

Setup for the tidal and flood hydraulic model for existing conditions included determination of the model area, bathymetry, mesh selection, and boundary conditions.

3.1 MODEL AREA

The model area covers Alamitos Bay, Marine Stadium, and Colorado Lagoon as shown in Figure 1. The model mesh covers a relatively large area. The ocean boundary (at an average contour elevation of -45 feet relative to the NGVD29 vertical datum) is approximately one mile from the shoreline. The side boundaries are also approximately one mile northwest and southeast from the project site. Designating the open model boundaries far from the area of interest minimizes boundary effects. The modeling mesh for the area from Marine Stadium to the offshore inside the arc in Figure 2 was provided by the consultants to the County of Los Angeles, Department of Public Works (Everest International Consultants, Inc).

3.2 BATHYMETRY

The Alamitos Bay and ocean bathymetry are based on data obtained from the National Oceanic and Atmospheric Administration (NOAA) chart 18749. The bathymetry of Colorado Lagoon and a portion of the Marine Stadium near the culvert connecting the Colorado Lagoon are based on a February 2004 survey by the Los Angeles County Department of Public Works (LACDPW). Design drawings of the culvert connecting Marine Stadium and the Colorado Lagoon were provided by the City of Long Beach. However, no recent survey data are available for the culvert condition since it was constructed in 1965. The county has indicated that a survey will occur in summer of 2004 and results may be available for future modeling efforts. The flow through the culvert is simulated as a rating curve in the RMA2 model. The rating curve is adjusted during the model calibration.

Figure 2 shows the bathymetry of the entire modeling domain, Figure 3 shows details of Colorado Lagoon. The project uses the NAD 83 California Zone 6 horizontal coordinate system and the NGVD29 vertical datum. English units (feet, feet per second, etc.) are used throughout the model.

3.3 MODEL MESH

The RMA2 model requires the estuarial system to be represented by a network of nodal points defined by coordinates in the horizontal plane and water depth, and elements created by connecting these adjacent points to form areas. Nodes can be connected to form 1- and 2-D elements, having from two to four nodes. The resulting nodal/element network is commonly called a finite element mesh and provides a computerized representation of the estuarial geometry and bathymetry. The results discussed herein correspond to 2-D analyses with the exception of the culverts leading to the Colorado Lagoon which is represented by 1-D elements.

The two most important aspects to consider when designing a finite element mesh are: (1) determining the level of detail necessary to adequately represent the estuary, and (2) determining the extent or coverage of the mesh. The model described in this section is numerically robust and capable of simulating tidal elevations, flows, and constituent transport with reasonable resolution. Accordingly, the bathymetric features of the estuary generally dictate the level of detail appropriate for the mesh.

There are several factors used to decide the aerial extent of a mesh. First, it is desirable to extend mesh open boundaries to areas which are sufficiently distant from the proposed areas of change so as to be unaffected by that change. Additionally, mesh boundaries must be located along sections where conditions can reasonably be measured and described to the model. Finally, mesh boundaries can be extended to an area where conditions have been previously collected to eliminate the need to interpolate between the boundary conditions from other locations.

The finite element mesh for the existing condition is shown in Figure 4. The mesh contains a section of ocean sufficiently large to eliminate potential model boundary effects. The lagoon portion of the mesh is bounded by the +6 foot contour relative to the vertical datum of NGVD29 considered to sufficiently contain the outermost extents of tidal and flood influence. The lagoon area mesh is shown in Figure 5.

The entire modeling area, approximately 5 square miles, is represented as a finite element mesh consisting of about 2,800 elements and 8,000 nodes.

3.4 BOUNDARY CONDITIONS

3.4.1 Tides

Since there are no tide stations at Alamitos Bay, the nearest Los Angeles Outer Harbor gage was used as the ocean boundary tidal condition as shown in Table 1. The diurnal tide range is approximately 5.49 feet from Mean Lower Low Water (MLLW) to Mean Higher High Water (MHHW) and Mean Sea Level (MSL) is at +2.82 feet relative to MLLW.

Water level measurement data provide astronomical tides and other components including barometric pressure tide, wind setup, seiche, and the El Nino Southern Oscillation. Tidal variations can be resolved into a number of sinusoidal components having discrete periods. The longest significant periods, called tidal epochs, are approximately 19 years. In addition, seasonal variations in MSL can reach amplitudes of 0.5 feet in some areas, such as Los Angeles Outer Harbor. Superimposed on this cycle is a 4.4-year variation in the MSL that may increase the amplitude by as much as 0.25 feet in San Pedro Bay. Water level measurement data are typically analyzed over a tidal epoch to account for these variations and obtain statistical water level information (e.g., MLLW and MHHW).

Table 1. Recorded Water Levels at Los Angeles Outer Harbor (1983-2001 Tidal Epoch)

Description	Elevation (feet, MLLW)	Elevation (feet, NGVD29)
Extreme High Water (1/27/83)	+7.82	+5.18
Mean Higher High Water (MHHW)	+5.49	+2.85
Mean High Water (MHW)	+4.75	+2.11
Mean Tidal Level (MTL)	+2.85	0.21
Mean Sea Level (MSL)	+2.82	0.18
National Geodetic Vertical Datum 1929 (NGVD29)	+2.64	0.00
Mean Low Water (MLW)	+0.94	-1.70
Mean Lower Low Water (MLLW)	0.00	-2.64
Extreme Low Water (12/17/33)	-2.73	-5.37

3.4.2 Parametric Mean Periodic (PMP) Tidal Series

A synthetic tidal series, referred to as a parametric mean periodic (PMP) tide developed by M&N (1994b), is used to simulate long-term average water levels for determining habitat area formation. The series matches the mean water levels (i.e., MHHW, MLLW, etc.) and phase differences of the existing tidal epoch. This provides short duration (days) tidal conditions similar to the 19-year tidal epoch as shown in Figure 6 to reduce modeling time while still generating accurate results.

3.4.3 Flood Flows to the Colorado Lagoon

A hydrologic analysis for the 1,130-acre watershed tributary to Colorado Lagoon was analyzed by the LACDPW in 2003. Under the existing condition, the 50-year return interval design storm hydrograph is shown in Figure 7. The peak flow rate from the watershed entering the Colorado Lagoon is 710 cubic feet per second (cfs). These flows were assumed to occur simultaneously with high tides at the lagoon to determine peak water levels in the lagoon.

3.5 MODEL CALIBRATION

RMA2 calibration involves matching model predictions with measured data by selecting appropriate input variable values to model [e.g., Manning's roughness coefficient (n), and turbulence exchange coefficients (eddy viscosity)].

The RMA2 User's Manual recommends ranges of values for Manning's roughness coefficient (n) and eddy viscosity to be used in the model (USACE WES, 1996b). The value of Manning's roughness coefficient (n) is a function of the characteristics of the hydraulic system and represents the roughness of the channel bed. As discussed in Chaudhry (1993), values can range from 0.011 to 0.075 or higher for natural rivers and estuaries. Relatively high values (0.04 to 0.05) are specified for rough surfaces, such as channels with cobbles or large boulders. Mid-range values (0.03) represent clean and straight natural streams. Low values (0.013 to 0.02) are specified for smooth surfaces, such as concrete, cement, wood, or gunite. Values of Manning's roughness coefficient (n) used for this analysis are in the middle range of the recommended values.

Eddy viscosity represents the degree of turbulence in the flow. In this application, the values range from 50 to 300 lb-sec/ft^2. The modeling grid size depends on and is limited by the Peclet number and eddy viscosity. The Peclet number is defined as $\frac{rV\Delta X}{E_{ij}}$, in which r, V, DX, and E_{ij} are the water density, velocity, grid size and eddy viscosity, respectively. In order for the solution to be stable, the Peclet number has to be less than 50. The Peclet number can be reduced by increasing the mesh density or by increasing the eddy viscosity. However, it is unrealistic and time-consuming to perform the modeling with a very fine grid. Therefore, a relatively high value of eddy viscosity is used in order to preserve numerical stability, and to streamline the modeling efforts.

Two tide gages were deployed on June 18, 2004, one at Marine Stadium and the other at Colorado Lagoon as shown in Figure 8. Water level data were downloaded from these two gages on July 16, 2004 and used to compare to model simulations for calibration. The gages are small cylindrical pressure transducers that record water levels.

The water levels and tide phase at Marine Stadium are very similar to those predicted at Los Angeles Outer Harbor. The measured low tides were truncated at elevation –2.6 feet

NGVD29 where the gage was mounted. The gage was mounted slightly too high to record the lowest low tides, but these data are sufficient to illustrate that tidal conditions at Marine Stadium are very similar to those at the ocean. Oscillations in the recorded water levels at Marine Stadium in the mid-day and weekend of June 26 and 27 may have been caused by passing boats.

The high tidal elevations at Colorado Lagoon were also close to the ocean tidal elevations when the gate at the culvert was opened as much as possible (Personal communication with City Marine Maintenance Department, Jeff Edwards 2004). The tide gate was lowered and blocked the upper portion of the culvert, partially closing it on June 30, 2004. The lag of high tides is about one hour. The recorded tides are shown in Figure 9. The low tides as shown in the Figure as a green line were only lowered to about –1 foot NGVD29 before the gate was partially closed, and the lag is about 3 hours. In the other words, the tide range in the lagoon is about 1 to 3 feet less than that in Marine Stadium and only the low tides are truncated by the culvert. High tides reach ocean conditions. The tides were further muted in July of 2004 after the gate was partially closed as shown in Figure 9. Therefore, only the tidal records from June 18 through June 29, 2004 as shown in Figure 9 were used in the model calibration. Calibration parameters were adjusted until model results approximated field measurements. The resulting calibration parameters are presented in Table 2.

Table 2. Setup Values for Model Calibration

Model Area	Manning's Roughness Coefficient (n)	Eddy Viscosity Coefficient (lb-sec/ft^2)
Lagoon Intertidal Areas	0.035	300
Lagoon Subtidal Areas	0.03	100
Marine Stadium Intertidal Areas	0.035	120
Narrow Channels and Marinas	0.025	150
Marine Stadium Subtidal & Alamitos Bay Areas	0.025	50
Nearshore Surf Zone	0.030	250
Offshore from surf Zone	0.02	200

The time step is a very important parameter in the modeling. Sensitivity tests were conducted and results showed that the RMA2 model becomes unstable with an increasing time step if the wetting and drying processes are considered. A time step of 0.1 hour was used in order for the solution to be stable and to reflect the dynamic tidal fluctuations and the flood flow hydrograph.

As previously discussed, a survey of the current culvert conditions was not yet available. Culvert maintenance has not been done since the culvert was constructed in 1965, and there may be substantial sediment deposits, debris, and marine growth in the culvert. Also, there may be a sill in the culvert entrance to the lagoon to maintain a minimum water level in the lagoon (personal communication with past City employee, George Johnson, 2004). The sill is a restriction to the lagoon circulation and truncates low tides in the lagoon. Therefore, the model's culvert invert elevation and capacity were adjusted in the model calibration to achieve the measured tidal elevations in the lagoon.

For the model calibration, predicted tides over the measurement period were downloaded from NOAA web site (NOAA 2004) and were applied at the model offshore boundary. Tidal elevations simulated by the model correspond well with those measured at the Marine Stadium Gage both in terms of tidal phase and range as shown in Figure 10. The low tides were partially cut off due to the gage not being mounted low enough. Oscillations in the recorded tides are likely boat wakes. Tidal elevations simulated by the model in the Colorado Lagoon also match well with the measured tides in both phase and tidal range as shown in Figure 11, but the simulated high and low tides are approximately two tenths of a foot lower than those measured. The modeling accuracy can be improved when more measured tide data are available this summer and the culvert survey results are provided by the County. However, the results are sufficiently accurate to quantify existing conditions.

3.6 HYDRAULIC MODELING RESULTS

The calibrated numerical model was applied to evaluate the hydraulic conditions under both dry and a 50-year storm conditions.

3.6.1 Dry Weather Condition

Under the dry weather condition, typically from May to October, the local storm drain inflow is negligible for the hydraulic regime. Tidal flows are the main driving force for the lagoon circulation and water exchange.

As shown in Figure 9, the measured data indicate the high tidal elevations in the lagoon are close to the ocean tides, and the lag is one hour. The low tides are significantly muted by one foot during the neap tidal cycle from June 24 to 27 and 2 - 3 feet during the spring tidal cycle from June 18 to 20 as shown in Figure 9, and the lag is about 3 hours. The water exchange between the lagoon and Marine Stadium was reduced by 1 to 3 feet per tidal cycle comparing to the full ocean tide range. Tidal muting and lag in the lagoon are due to the long culvert as a choke to the lagoon, and it is an indication of a restriction to circulation. The data also show that the tidal ranges were further reduced or muted while the tide gate was partially closed. The tide gages were left in place for another month and the gate was opened as much as possible to provide data to be used to separate effects of the gate from those of the culvert.

The tide range and phase in the Marine Stadium are very similar to the ocean indicating that Marine Stadium has much better tidal circulation. That is evidenced by a visual comparison of the clarity of water in these two different water bodies. The water in Marine

Stadium is clear and very similar to the ocean. However, the lagoon water is more turbid and less clear.

3.6.2 50-Year Storm Condition

Under the 50-year storm condition, the peak storm flow was assumed to occur simultaneously with the high tide at the lagoon (corresponding to the MHHW tide at the ocean boundary) to determine the peak water level in the lagoon. The predicted water levels are shown in Figure 12. The peak water level in the lagoon reaches 5.7 to 5.9 feet NGVD29, the same elevation as the boundary of the lagoon along a short reach of about 200 feet near the intersection of Colorado Street and Eliot Street. The remaining lagoon boundary varies from elevation 6.38 feet to around 8.0 feet (LACDPW, February 2001). Figure 12 also shows it would take a few days for the lagoon water level to drop to within the normal tidal fluctuations.

4.0 SUMMARY

The RMA2 numerical model was constructed to quantify existing lagoon hydraulics. The model was calibrated with measured tidal data and applied in assessing both the dry and wet weather tidal and flood hydraulic conditions.

Under the dry weather condition, the model results suggested that the low tides in the Colorado Lagoon were muted under the current open gate condition (the gate is lifted as much as possible). The low tides were cut off about 2 feet compared to the ocean tide. Tidal circulation is significantly reduced by the culvert compared to Marine Stadium – the water source. The mean tidal elevation in the lagoon is about +0.7 feet NGVD29. The tidal fluctuations at Marine Stadium were very similar to the ocean. Therefore, the culvert is the restriction on lagoon circulation.

Under the 50-year storm, and during the ocean high tide with the culvert open, the model results suggested that the peak water level in the lagoon reaches +5.7 to +5.9 feet NGVD29, the same elevation as a portion of the levee top elevation near the intersection of Colorado Street and Eliot Street. Flood protection for this location should be considered for the future.

The tidal circulation and flood flows at the lagoon under culvert design conditions will be analyzed in the future task of evaluating restoration alternatives using the model, as it is sufficiently calibrated and accurate to predict results and compare alternatives.

Based on this hydraulic study, the following recommendations should be considered for future planning:

- Build a flood barrier to provide the 50-year storm protection for surrounding properties along Colorado Avenue near Eliot Street;

- Establish operational procedures such that the culvert gate remains completely open, especially during storm events. The City should also check whether a sill exists on the bottom of the culvert entrance to the lagoon and consider its removal to increase flood flow conveyance and improve the dry weather tidal circulation.

- Clean the culvert by removing debris/sediment deposits and marine growth on a regular schedule; this will also improve the tidal circulation and increase flood flow conveyance, and ultimately lower the flood water level and improve water quality in the lagoon.

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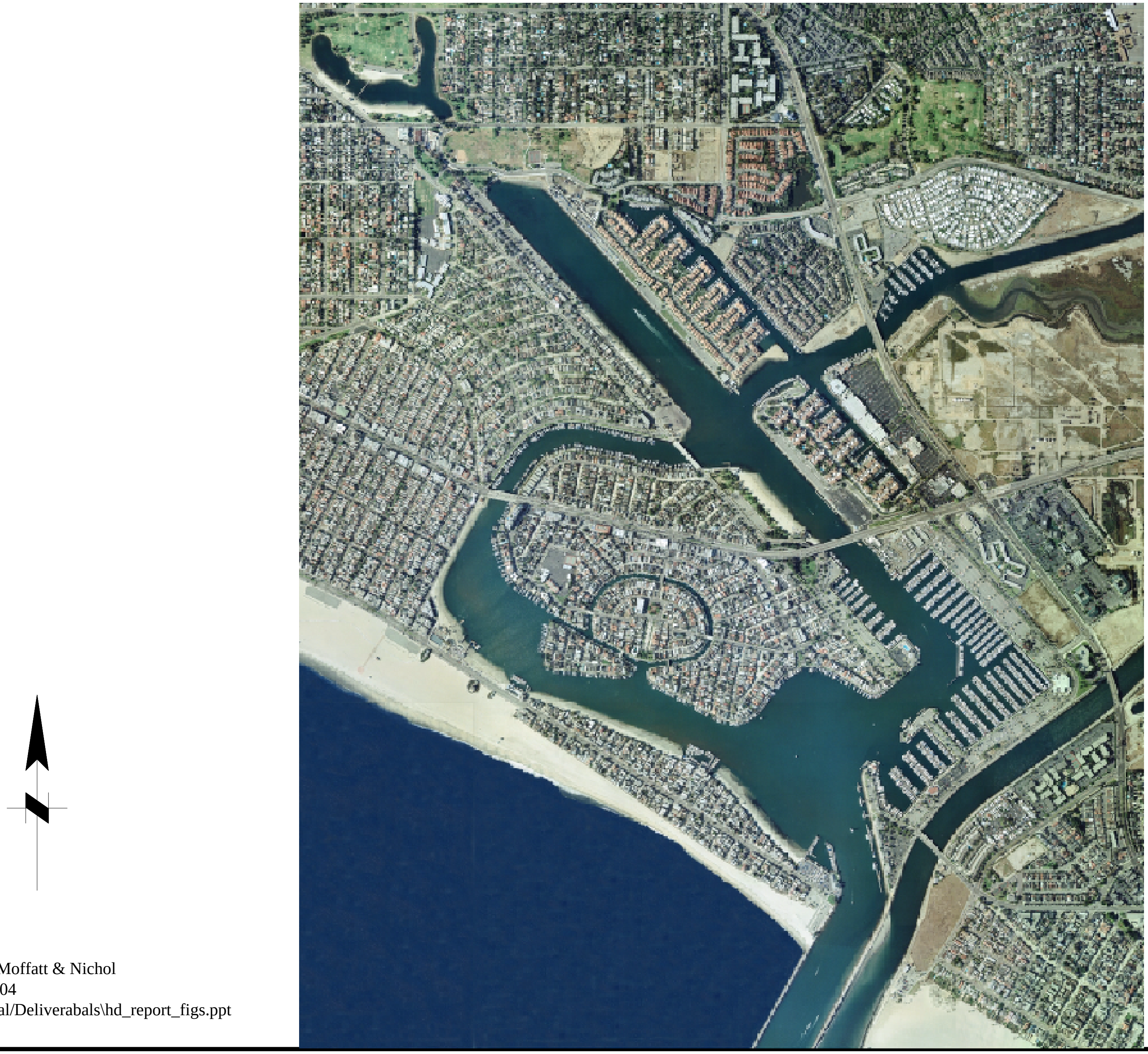

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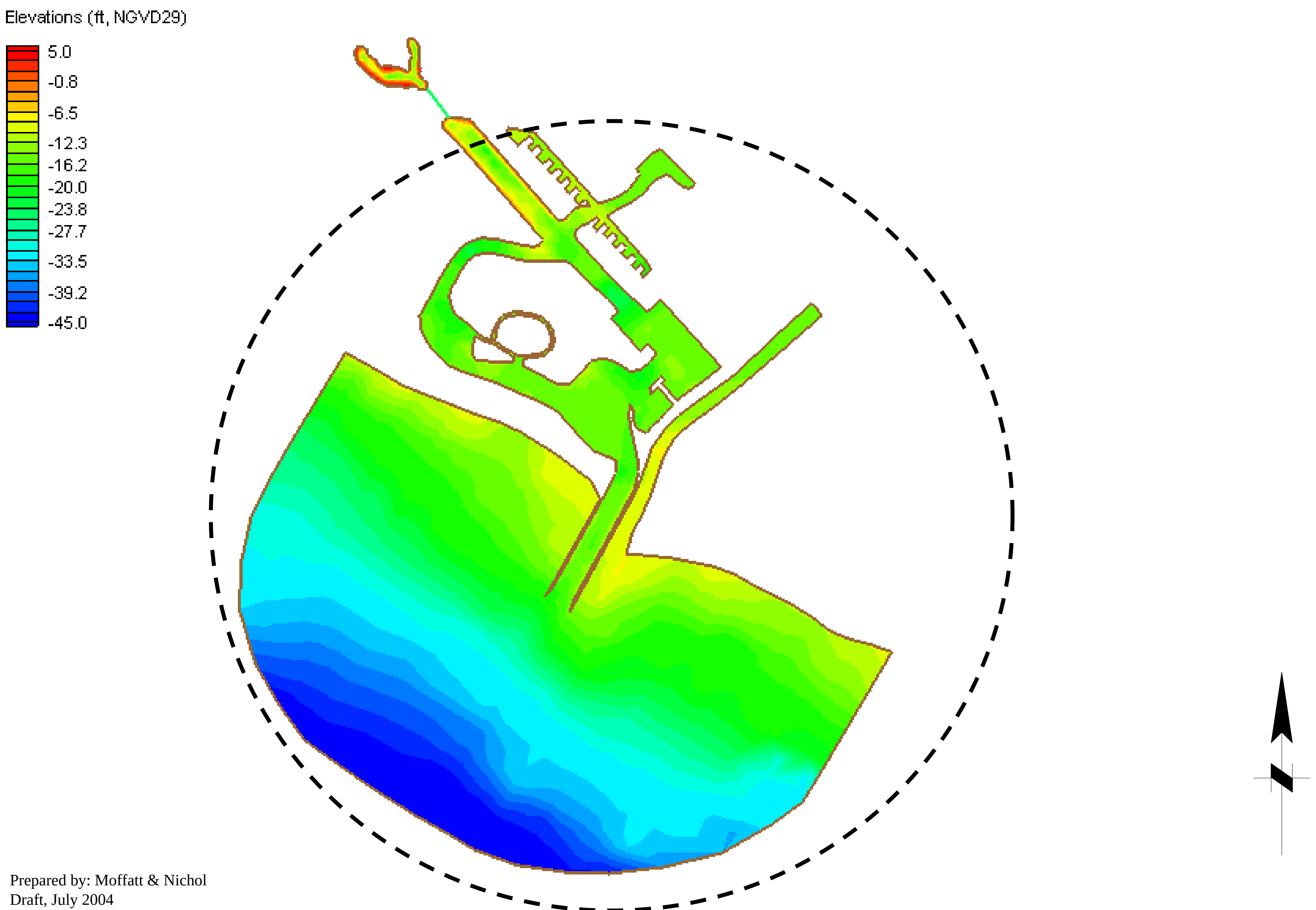
Colorado Lagoon Restoration Feasibility Study

Hydrodynamic Modeling Area

Figure 1



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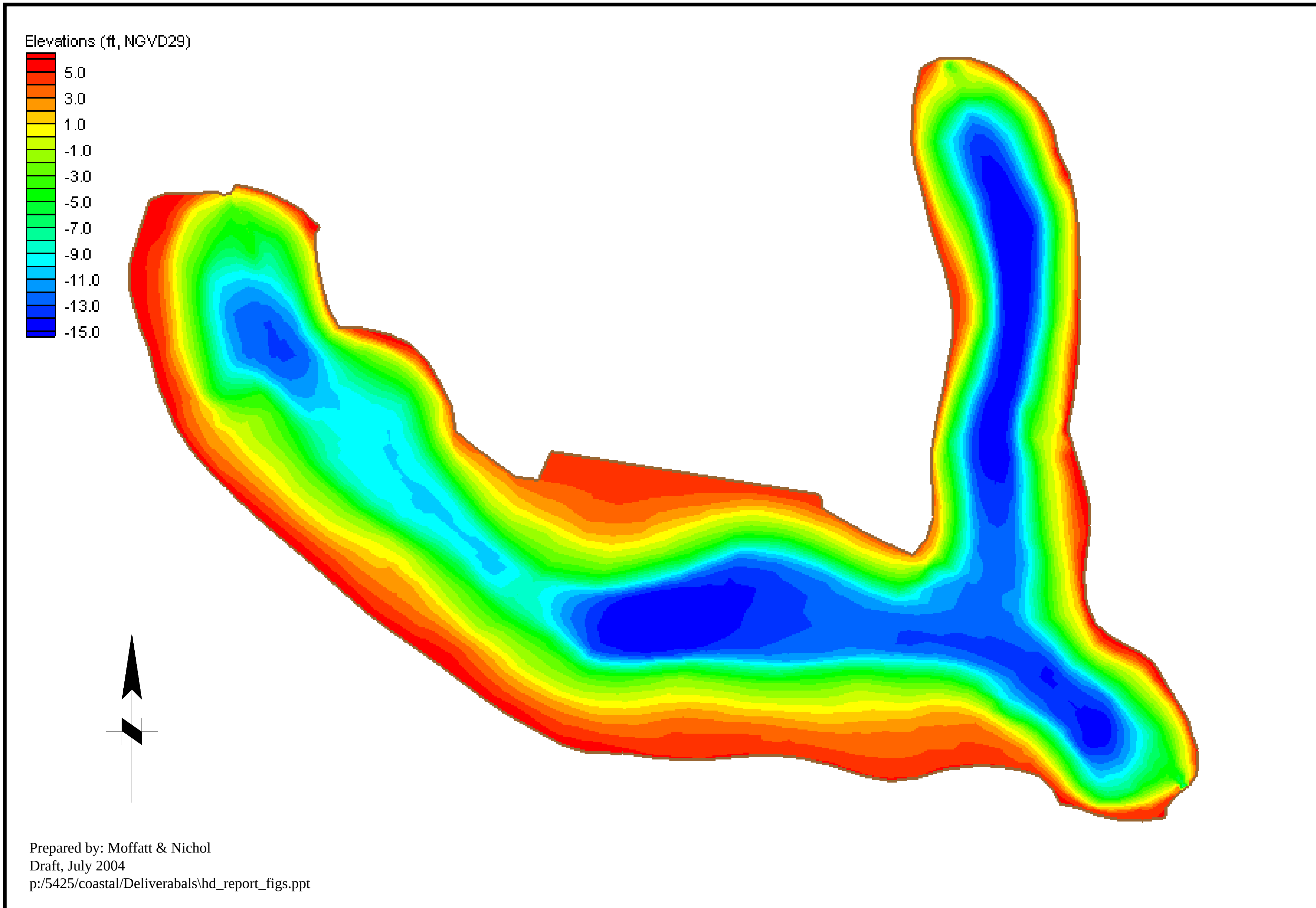
Colorado Lagoon Restoration Feasibility Study

Bathymetry of Modeling Area

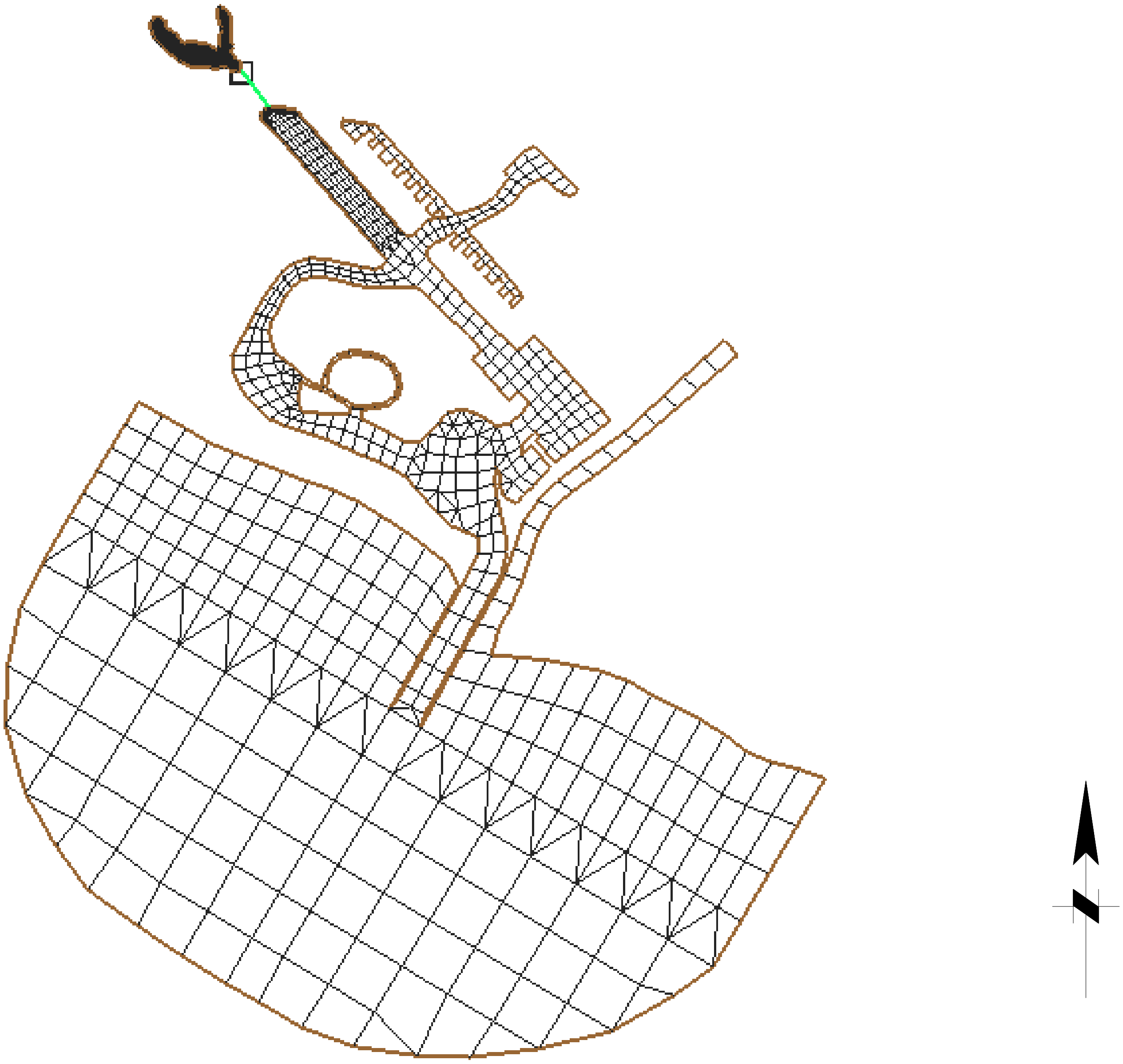
Figure 2



Colorado Lagoon Restoration Feasibility Study

Bathymetry of Colorado Lagoon

Figure 3



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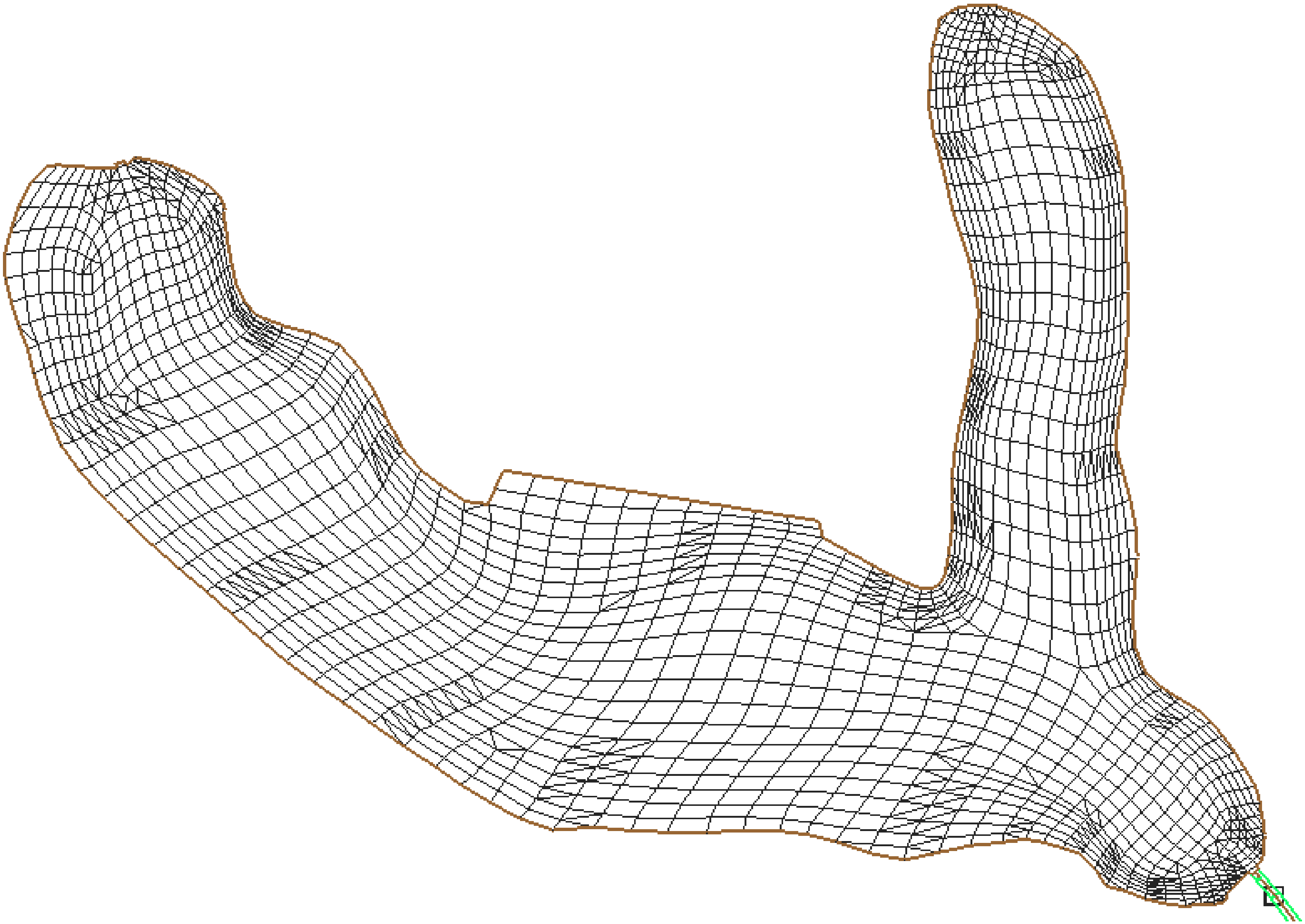
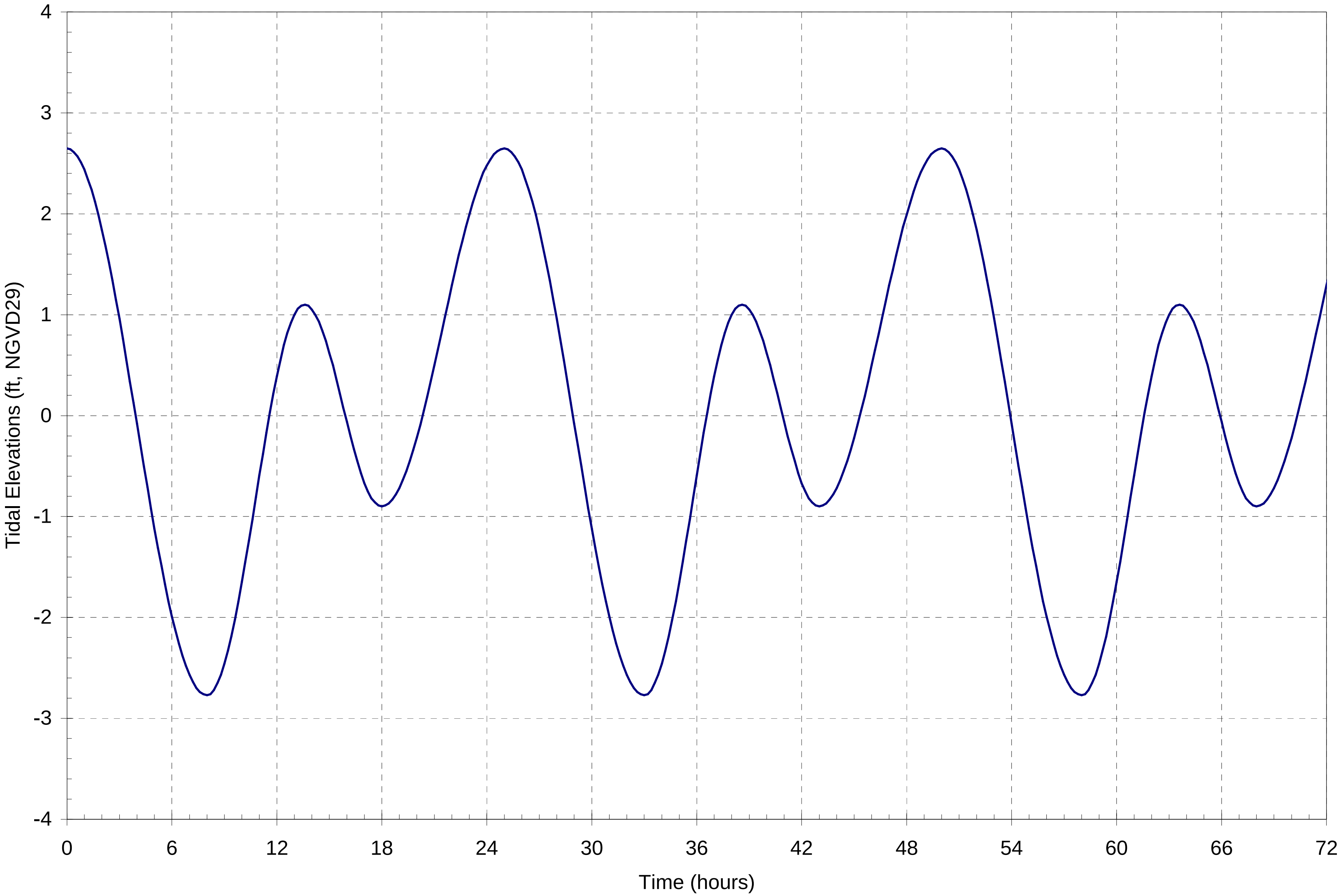
Colorado Lagoon Restoration Feasibility Study	Finite Element Mesh for Modeling Area	Figure 4



Colorado Lagoon Restoration Feasibility Study

Finite Element Mesh for Colorado Lagoon

Figure 5



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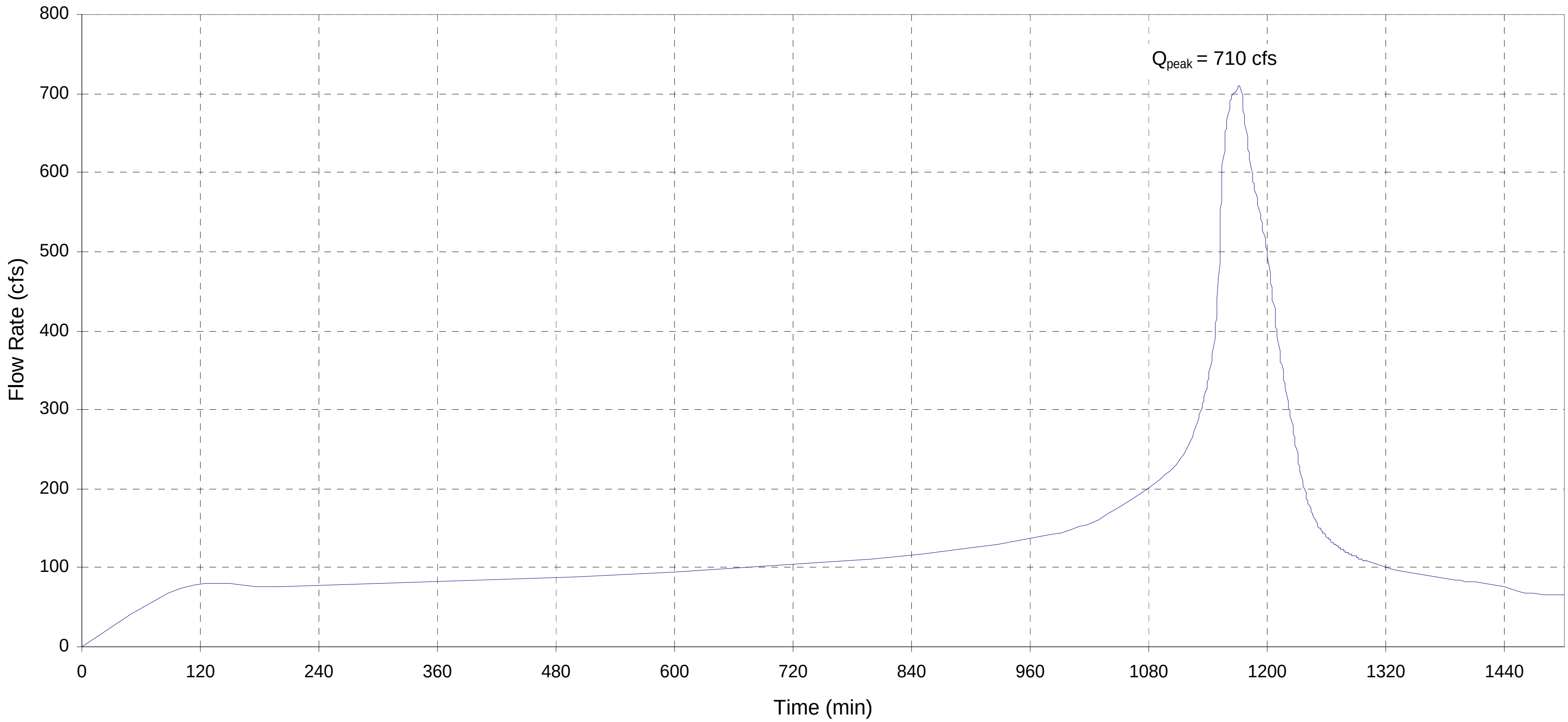
Colorado Lagoon Restoration Feasibility Study

Parametric Mean Periodic (PMP) Tidal Series

Figure 6



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Colorado Lagoon Restoration Feasibility Study	50-Year Hydrograph of Existing Conditions	Figure 7

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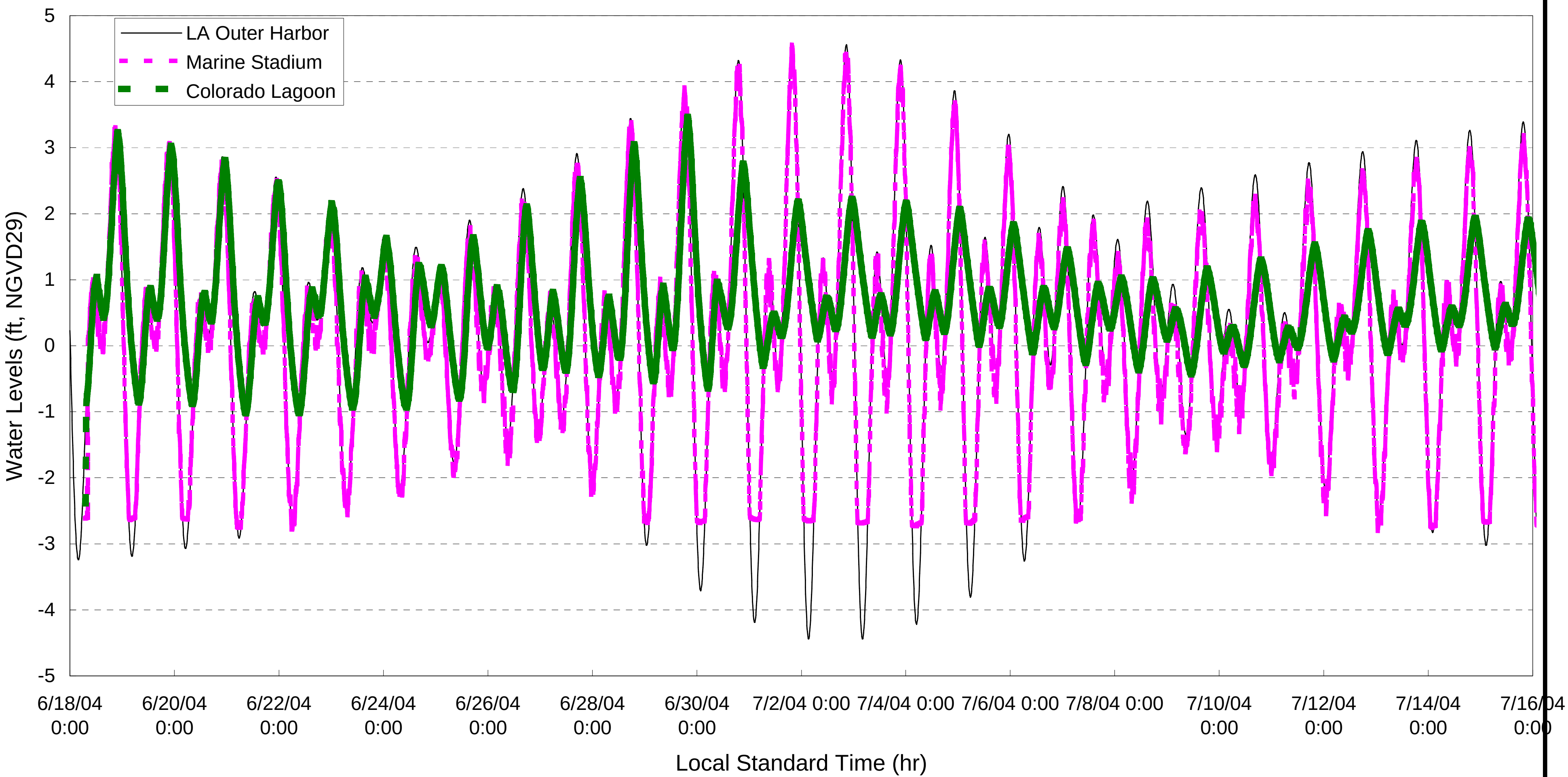
Colorado Lagoon Restoration Feasibility Study	Tidal Gage Locations	**Figure 8**



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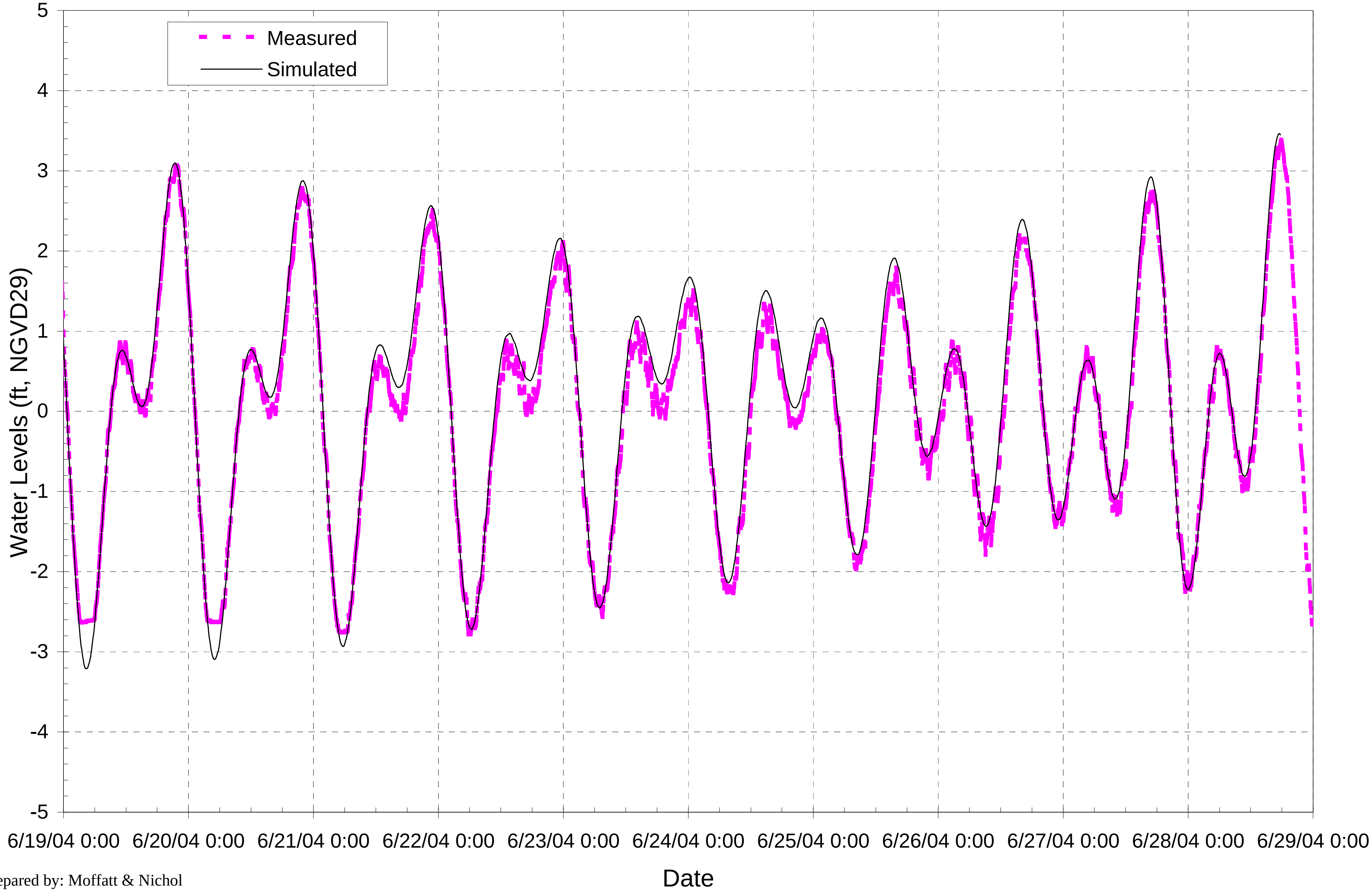
Colorado Lagoon Restoration Feasibility Study	Tidal Elevation Comparison	Figure 9



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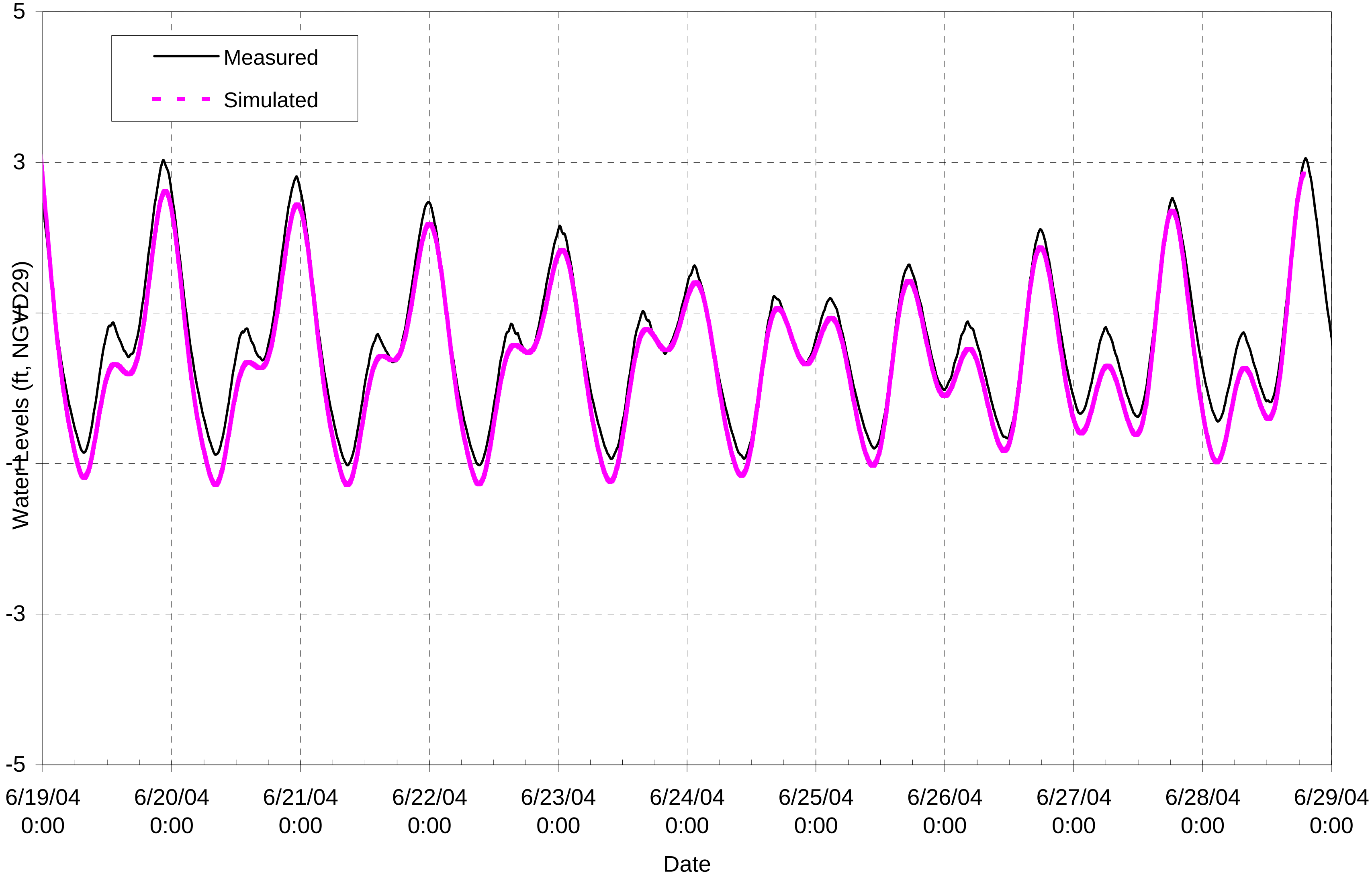
Colorado Lagoon Restoration Feasibility Study

Comparison of Simulated Tides with Measured at the Marine Stadium

Figure 10



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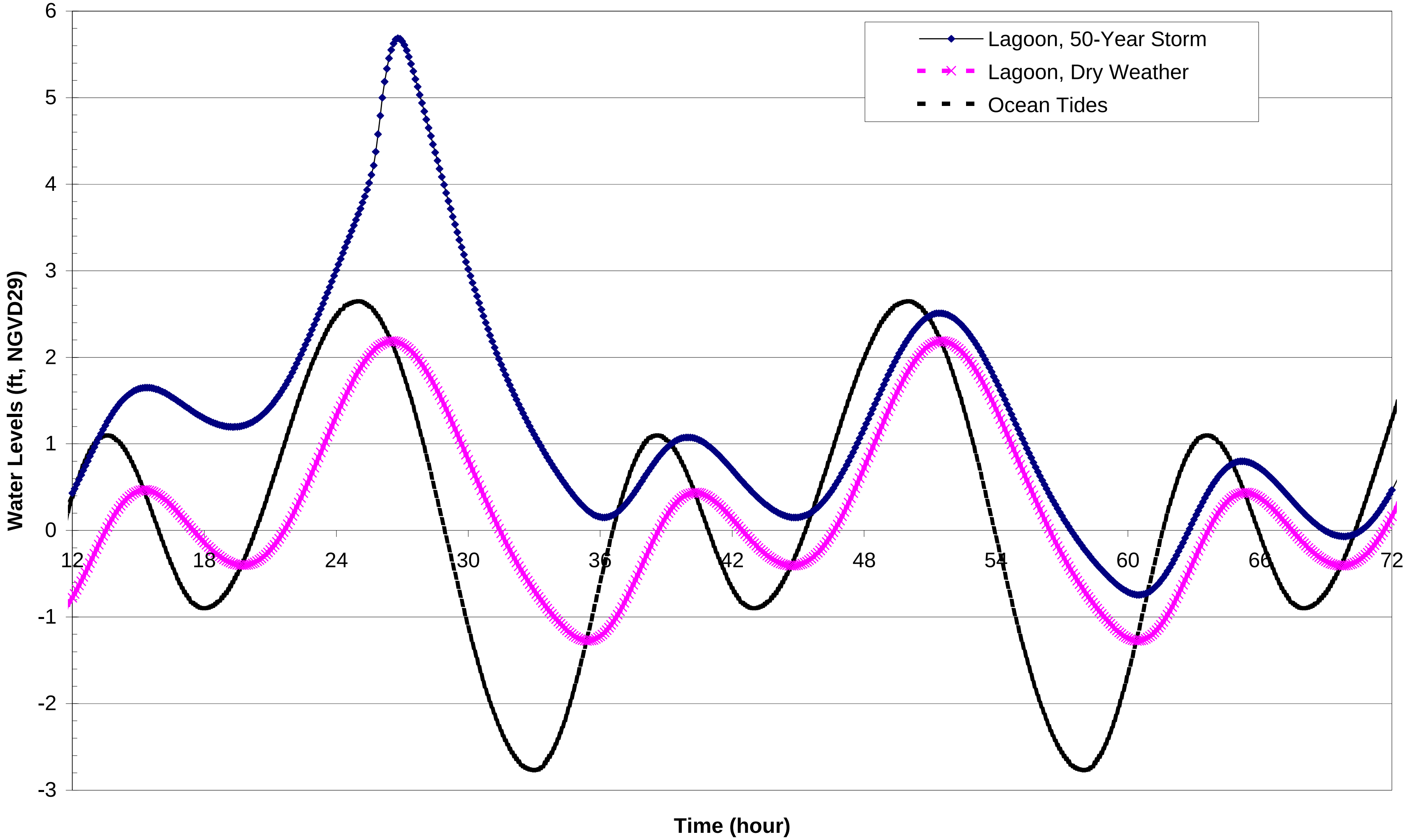
Colorado Lagoon Restoration Feasibility Study	Comparison of Simulated Tides with Measured at the Colorado Lagoon	**Figure 11**



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Colorado Lagoon Restoration Feasibility Study	Comparison of Water Levels	Figure 12